Mon. Not. R. Astron. Soc. **000**, 000–000 (0000) Printed 2 February 2008 (MN LaTeX style file v2.2)

Monitoring the spin up in RX J0806+15

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2 February 2008

ABSTRACT

RX J0806+15 shows a prominent intensity variation on a period of 321.5 sec. This has widely been interpreted as the binary orbital period, although this remains controversial. We have been monitoring the precise period of RX J0806+15 for a number of years. By measuring the rate of change we can help distinguish between competing physical models. New observations obtained between Nov 2003 and Feb 2004 show that the period decrease already reported by Hakala et al (2003) and Strohmayer (2003) is continuing. We discuss how reliably we can determine the period of RX J0806+15 using our technique and evaluate the current models which have been proposed to account for the observational properties of this source.

Key words: Stars: individual: RX J086+15 – Stars: binaries – Stars: neutron stars, cataclysmic variables

1 INTRODUCTION

Recently three sources have been discovered which show very stable intensity variations on timescales of less than ∼10 mins: RX J0806+15 (321 sec, Ramsay, Hakala & Cropper 2002, Israel et al 2002); RX J1914+24 (569 sec, Cropper et al. 1998, Ramsay et al. 2000, 2002) and ES Cet (620 sec, Warner & Woudt 2002). Furthermore, these are the only periods which have conclusively been detected in these systems. As such these periods have generally been taken to reflect the binary orbital period. Such short periods imply a very small binary dimension indicating that both stellar components are extremely compact. However, their nature remains controversial (see Cropper et al 2003).

One of the best techniques to resolve their nature is to determine their period extremely accurately at different epochs. For binaries in which mass transfer is occurring the binary orbital period should increase over time. In contrast, in the case of the unipolar inductor (UI) model (Wu et al 2002) the orbital period is expected to decrease over time. On the other hand, Norton, Haswell & Wynn (2004) argue that the observed period is the spin period of the accreting white dwarf and that any period decrease is consistent with that seen in the weakly magnetic cataclysmic variables, the intermediate polars: IPs.

In the case of RX J0806+15, Hakala et al (2003) and Strohmayer (2003) have presented evidence that the 321 sec period is decreasing at a rate consistent with that expected if the system was being driven entirely by gravitational radiation (ie consistent with the UI model). More recently, Strohmayer (2004) has found evidence that the period of RX J1914+24 is also decreasing over time.

However, these results are controversial, with Woudt & Warner (2003) claiming that there is difficulty in correctly identifying the appropriate peak in the power spectra at different epochs. Clearly, it is essential to monitor the period of these systems. We have a programme of optical observations of RX J0806+15 to do this. In this short paper we present our latest observational results and relate these to the results of Hakala et al (2003). We discuss the implications of these results regarding the nature of this system.

2 OBSERVATIONS

In order to measure possible period changes in RXJ0806+15, we have obtained data from the Nordic Optical Telescope (NOT) and also the Isaac Newton Telescope (INT), both located in La Palma. Table 1 shows the observational log. The observations made using the INT were made using the Wide Field Camera and were part of a project to detect objects varying on short timescales (Ramsay & Hakala in prep). White light exposures were 30 sec in duration, but the readout time was of the order of 40 sec implying a poor efficiency and an effective time resolution of only 70 sec. In contrast, the observations made using the NOT were dedicated to RX J0806+15. These observations were carried out using ALFOSC in imaging mode, again in white light. The approximate time resolution was 20 sec (15 sec integration time) and we selected only a small sub-window (approx 200x200 pixel) for fast readout. In all our observations,

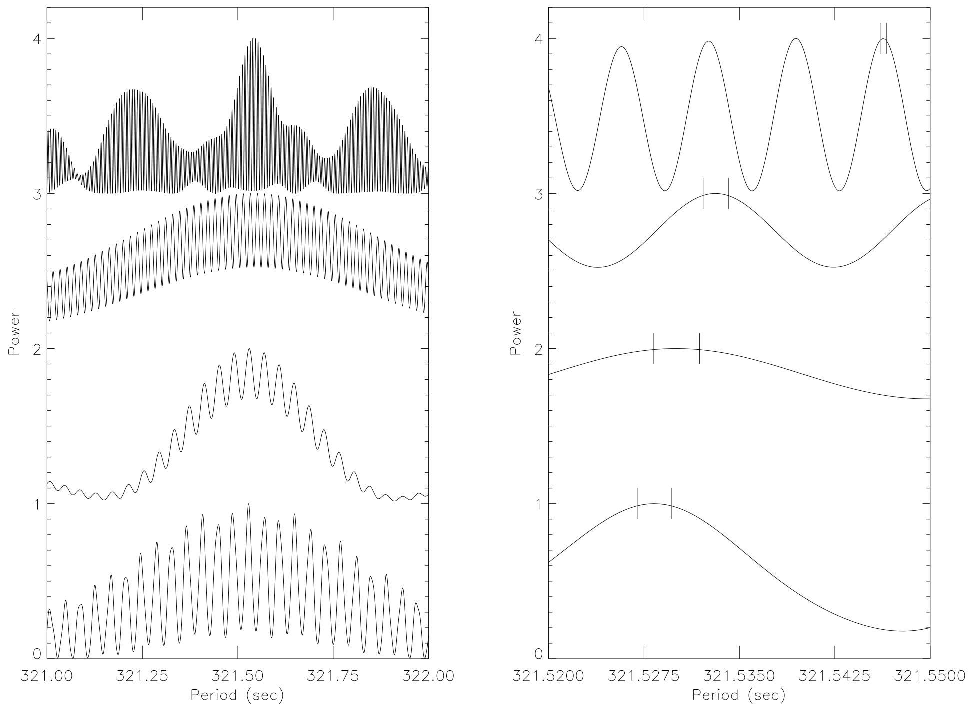

Figure 1. The normalized (maximum equals 1.0) power spectra based on all the observations available to us so far. The plots (from top to bottom, shifted by 1.0 in Y-direction and in chronological order) are *ROSAT* data, VLT 2001-NOT 2002 data, NOT 2003 data (all presented in Hakala et al 2003) and INT 2003-NOT 2004 data. The short vertical lines around the preferred peaks indicate the $\pm$ 3σ error limits for the best periods.

Telescope	Dates	Duration
INT	2003-11-29	2hr 6min
NOT	2004-01-18	8hr 4min
NOT	2004-01-19	7hr 42min (with 4hr 12min gap)
NOT	2004-02-17	4hr 46min

Table 1. The observation log of our INT 2003 and NOT 2004 observations.

Dataset	mid HJD	Period
ROSAT	2449738.010	321.54629 $\pm$ 0.00008 sec
VLT+NOT 2001-02	2452281.416	321.53314 $\pm$ 0.00034 sec
NOT 2003	2452649.529	321.53007 $\pm$ 0.00060 sec
INT+NOT 2003-2004	2453030.395	321.52832 $\pm$ 0.00044 sec

Table 2. The periods resulting from our analysis together with the errors from Monte Carlo simulations.

frames were bias corrected and flat-fielded in the usual manner. Star B (Ramsay, Hakala & Cropper 2002) was used as the comparison. The date of the mid-point of the exposures were heliocentric corrected.

3 PERIOD ANALYSIS

We used the Lomb-Scargle power spectrum to search for the best fit period of the combined INT and NOT light curve. The best fit period is 321.52832 sec and the resulting power spectrum is shown in Figure 1 (lower curves). To determine the error on this period we simulated 1000 datasets using original time bins together with a sinusoidal equal amplitude variation with noise added at the observed level. We find an error of 0.00044 sec. We show how this period relates to the previous observations in Figure 2. This latest period measurement confirms that the period is shortening (spinning up) over time.

Hakala et al (2003) used 3 subsets of data to determine the change in period of RX J0806+15. They found a period decrease at a rate of $3.14{\times}10^{-16}$ Hz/s or $6.11{\times}10^{-16}$ Hz/s depending on which period they chose as the 'real' period determined from *ROSAT* data. Based on this new period determination, we can rule out the shorter of the two *ROSAT* periods (321.5393 sec), (assuming the orbital period is spinning up at a regular rate). Taking the longer of the *ROSAT* periods and the other period measurements given in Hakala et al (2003) with that here, we find that the system is spinning up at a rate of $6.00{\times}10^{-16}$ Hz/s ($\pm 1.0 \times 10^{-17}$ Hz/s).

4 REFINED ERROR ANALYSIS OF THE ROSAT DATA

Our method of determining the periods has been criticised by Woudt & Warner (2003). While they agree with our error estimate for each power peak they contend that we cannot be certain that we have identified the correct peak. We now address this concern using two different techniques.

First we took the *ROSAT* data (barycentrically corrected) and binned it into 10 sec bins. We then folded it on

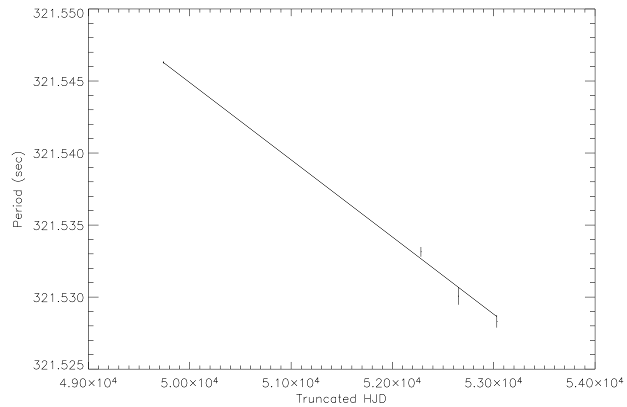

Figure 2. The period change of RX J0806+15 over time: the y-error bar reflects the error on the period.

the shorter of the *ROSAT* periods (321.5393 sec, the highest peak in *ROSAT* power spectrum) to obtain an average light curve shape (with 30 phase bins). To produce synthetic data with the exactly same pulse shape and counting statistics, we used the same *ROSAT* time points and for each time point created a count rate using Poisson statistics with the mean count rate for that particular phase interpolated from the phase binned folded light curve. We then created 10000 simulated datasets and ran the Lomb-Scargle analysis on these datasets. In 84 % of cases, the highest power peak is the true period. In the remaining 16 % of cases the highest peak is one of the neighbouring (alias) peaks, which have equal probability. Therefore, the peak corresponding to the 'true' period is *never* lower than the second highest of all peaks in the power spectrum. In order to check our analysis against using a 'wrong period' for building up the *ROSAT* pulse shape (used as a basis for our simulations) we repeated the simulations using 321.5463 sec (the second highest peak) period for folding instead. The results from this test were identical to the earlier simulation.

The simulations described above only account for photon noise in the data. If one assumes that there could be secondary effects in the *ROSAT* data (like strong red noise or phase jitter due to the emission region moving on the primary surface), then these could potentially degrade our simulations. In order to account for these effects we have also performed another type of (limited bootstrap) simulation. We first take a period (321.5463 sec) and proceed by computing the orbital phase for each of the original data-points (as in the first approach). However, instead of trying to define any mean pulse shape, we now use the actual *ROSAT* data-points to generate synthetic light curves. We define a 'phase correlation length' (pcl) to be the maximum offset in orbital phase within which we can shuffle data-points. We then take each of the time points and select the flux value for that point from a pool of data-points that includes all the data with orbital phase within the ± 1 pcl interval.

The main difficulty of this approach is the choice of the pcl value. Firstly, one can take random pairs of *ROSAT* data-points and see how the mean correlation between the pairs depends on their offset in binary phase. In case of significant correlation (red noise or phase jitter), one would expect a break in the mean correlation vs. phase offset diagram at the value corresponding to the correct correlation length. However, there is only a very small effect in such plot at pcl = 0.04-0.05. Secondly, one can run the simulations at different pcl values and measure when the peak distribution in the periodogram starts to change significantly. This happens when the used pcl value is larger than the real correlation length in the data (at pcl $\sim$ 0.025 -0.03). Using simulations with pcl=0.025, we find that in 78.2% of the cases the highest peak is the true period. In 20.3% of the cases the true period is next to the highest peak and only in 1.5% of the cases the true period is lower than the second highest peak. These results support our findings from our first (Monte Carlo) simulations.

Our simulations imply that the highest peak in the *ROSAT* data (321.5393 sec) is either the true period or *next to* the true peak (with 98.5% confidence). This alone would still allow 321.5393, 321.5463 or 321.5321 sec to be the true period. However, the measured two highest peaks in actual *ROSAT* data are 321.5393 and 321.5463 sec, which (based on our simulations) rules out the 321.5321 sec period (at the 98.5% level). However, we also have additional information from our three optical period measurements. If we use only these, we can then estimate what the period would have been at the time of the *ROSAT* observations. This exercise implies 321.54968 $\pm$ 0.0019 sec. Only one of the *ROSAT* periods, namely 321.5463 sec, is within these limits.

Using our simulations we can also compute the error directly for the *ROSAT* period. The error for any single peak in the *ROSAT* power spectrum is significantly reduced, and is found to be 0.00008 sec instead of 0.00040 sec, quoted earlier by Burwitz & Reinsch (2001) and Hakala et al. (2003). The earlier error estimates were computed directly from the power spectrum assuming Cash statistics, whilst here the error is defined as a standard deviation of the best period from the Monte Carlo simulations.

Our results show that the aliasing problem for the *ROSAT* data is not as serious as claimed by Woudt & Warner (2003). Their conclusion was based on using their ES Cet *optical* data to mimic the *ROSAT* data sampling. Although they can mimic the *sampling* of data, their optical data cannot be used to mimic the X-ray modulation shape nor the counting statistics, which probably resulted in an overestimation of the sampling problem. The on-off type X-ray modulation is very different in shape when compared to the quasi-sinusoidal optical modulation. This implies that the phase information of the X-ray data is more accurate, which in turn implies that much more optical data would be required to match the 'period resolving power' of the X-ray power spectrum.

Woudt & Warner (2003) also criticize the period determination for the first of our optical datasets (Hakala et al. 2003). They claim that the aliasing problem prevents us from measuring the true period. However, the analysis of the aliasing structure reveals that the possible periods for that dataset are 321.515, 321.534 and 321.552 sec. If these values are compared against all the other period measurements (especially the two latest observations), it is immediately clear that only one of the periods, namely 321.534s, is possible.

5 DISCUSSION AND CONCLUSIONS

Our observations confirm the results of Hakala et al (2003) and Strohmayer (2003) who find that RX J0806+15 is spinning up. We find a spin-up rate of 6.0×10^{-16} Hz/s – consistent with that determined using the 'long' *ROSAT* period as found by Hakala et al (2003). If we have correctly identified the 321 sec period as the orbital period, the fact that the orbital period of RX J0806+15 is spinning up puts a question mark against accretion driven models. It does not rule them out since this could be just a secular change as seen in other binaries rather than a long term change. On the other hand it is spinning up at a rate consistent with that of being driven purely by gravitational radiation, which is what is predicted by the UI model (Wu et al 2002). If the 321 sec is identified with that of the spin period of the primary star (as suggested in the IP interpretation, Norton et al 2004), then the spin up is consistent with that seen in other IPs. We now discuss the relative merits of these two models in relation to RX J0806+15.

The applicability of the UI model to RX J0806+15 rests on the 321 sec period being correctly identified as the binary orbital period. If a second, longer, period can conclusively be identified then that would have a strong claim to be the binary orbital period and the UI model would therefore not be relevant to this source. On the other hand this model can account for all the observational properties, including the rate of spin up. It has been claimed that since Hydrogen is blended with Helium in the weak emission lines of RX J0806+15 (Israel et al 2002) this argues against all double degenerate models, including the UI model, (Norton et al 2004, Reinsch, Burwitz & Schwarz 2004). This is because the minimum orbital period for a degenerate Hydrogen-rich companion is ~30 min (Rappaport, Joss & Webbink 1982). However, even for Helium-rich stars, a measurable amount of Hydrogen is still present in white dwarfs (eg Friedrich et al 2000). We conclude therefore that the presence of weak Hydrogen emission lines in the spectrum of RX J0806+15 does not rule out the double degenerate models and that the UI model is still a viable model for RX J0806+15. Indeed, it can account for all the observational properties of this system.

We now consider the IP model developed by Norton et al (2004). In this model the 321 sec period represents the spin period of the stream accreting white dwarf. The fact that a second longer period has not been detected is explained by the system being a face-on binary system and hence there is no observational signature of the binary orbital motion (Norton et al 2004). Photometric observations extending into the IR by Reinsch et al (2004) argue against a typical main sequence secondary star as is typical in IPs. Norton et al (2004) suggest that in RX J0806+15 the secondary is a brown dwarf. They also note that a double degenerate IP model is possible. However, they argue that this is unlikely because of the presence of Hydrogen in its optical spectra. Again, we do not consider this is a valid reason for excluding this model. The IP interpretation has been criticised because in contrast to all other IPs, there are no strong emission lines in either RX J0806+15 or RX J1914+24. Norton et al (2004) argue that most of the line emission originates near the base of the accretion column and is obscured by the stream having a high optical depth. However, the strongly magnetic systems, the polars, which have a virtually identical stream geometry to that proposed by Norton et al (2004), show stream emission extending relatively far from the accreting white dwarf and not just from the base of the accretion column. We conclude that the absence of strong emission lines in these systems is a drawback for this model.

The nature of both RX J0806+15 and RX J1914+24 remains uncertain. Our current set of period measurements span less than ten years. Even if both these systems appear to be spinning up at a rate expected from general relativity, it is not yet *certain* that this is the cause for the spin up. However, we believe that the UI model remains, at this stage, the model which best accounts for the observational properties of RX J0806+15. Perhaps the definitive observations will be phase-resolved spectroscopy - if the weak emission lines are modulated on a 321 sec timescale, then that would be strong evidence that this period is indeed the binary orbital period.

6 ACKNOWLEDGMENTS

PJH is an Academy of Finland research fellow. Based on observations made with the Nordic Optical Telescope, La Palma. The data were obtained with ALFOSC, which is owned by the Instituto de Astrofisica de Andalucia (IAA). Observations were also made using the INT Wide Field Camera. We gratefully acknowledge the support of the staff at both Observatories.

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